Real-Time Electron Dynamics in Si Transistors I

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Glasses are perhaps the most common form of condensed matter. They include polymers, molecular glasses, gels, spin glasses, disordered ferroelectrics, etc. Glassy phenomena are exhibited also by a variety of other materials, such as high temperature superconductors. However, glassy behavior remains one of the most fundamental, unresolved problems in condensed matter physics.

Here we present results obtained using a magnetic field to explore the glassy behavior of electrons in Si field-effect transistors – the basic building blocks of Si technology. The study of the changes of the electrical conductivity (*i.e.* current) with time shows that glassy behavior in this system results from the intricate interplay of the omnipresent impurities and the Coulomb interaction between electrons (*i.e.* between their electrical charges). This information is an important step in trying to achieve a detailed, microscopic understanding of the glassy behavior.

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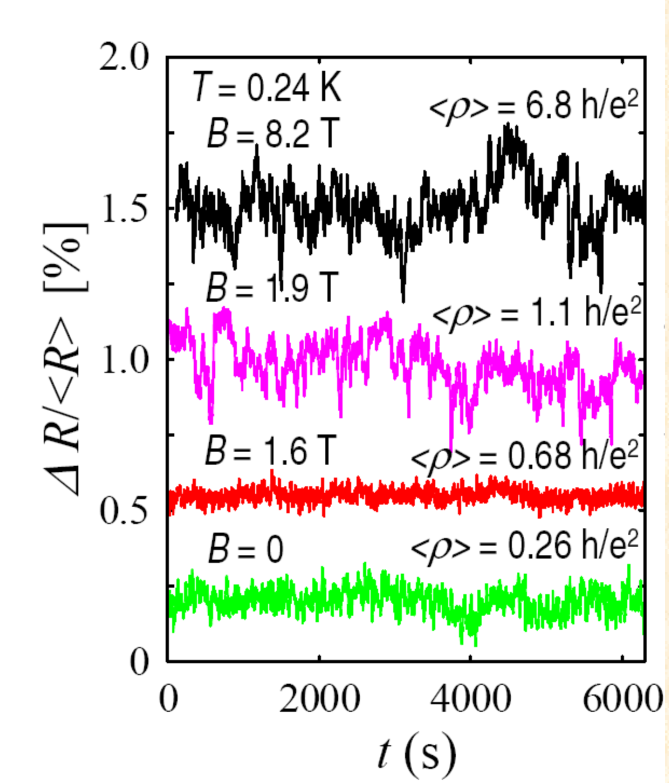

Figure 1. Different curves show the effect of magnetic field B on the relative fluctuations of resistivity (or conductivity) with time t (<…> denote averaging over time). The large changes in the signal in the top two curves correspond to large, collective rearrangements of electrons characteristic of the glassy regime.

We discovered earlier that, under certain conditions, namely when the number of electrons per unit area of the device is relatively small and at temperatures of less than a few tenths of a degree above absolute zero, the current flowing through a Si transistor shows some very slow changes with time, of the order of several hours or even much more. Such slow dynamics is common to all types of glassy materials. Since glassy behavior represents one of the most fundamental, unresolved problems in condensed matter physics, these devices are a convenient tool for studying glassy phenomena. For example, if a sufficiently strong magnetic field is applied parallel to the Si/SiO_2 interface in these transistors, the spins of all electrons will line up and point in the same direction without affecting the motion of the electrons. We have used that technique in this experiment, and monitored the electron dynamics by recording the changes of the current with time. We have established that the slow dynamics persists even when all the electrons' spins point in the same direction. This indicates that it is not the spins, but the electron charges that are responsible for glassy behavior. This information is important in trying to develop a detailed, microscopic understanding of the glassy phenomena. In addition, understanding of such current noise is important for the development of new devices for quantum computing. This work was published in the June 4, 2004 issue of Physical Review Letters.

Real-Time Electron Dynamics in Si Transistors II

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Education:

2 undergraduate students (REU summer interns),
1 graduate student,
1 post-doc.

Broader Impacts:

- **a special lecture on this topic was presented to a large group of REU and RET (Research Experiences for Teachers) participants at the National High Magnetic Field Laboratory in Tallahassee, FL**
- **this research has potential technological importance because understanding of the microscopic processes in many novel materials will allow us to design new materials for specific applications; in addition, understanding of the current noise in Si devices is important for the development of new devices for quantum computing**

Figure 2. Alex Vitkalov, one of the undergraduate summer interns, shown in the PI's lab.